# CHAPTER 5. BASIC SURFACE BLASTING TECHNIQUES

## 5-1. Introduction.

a. Rock blasting may be conducted for removal of rock, for control of excavated rock surfaces, and for control of blasted rock sizes. One project may require all types of blasting. For example, the construction of a large dam often requires removal of millions of cubic yards of overburden and rock, some of which may be wasted but much of which must be used for fill, riprap, and aggregate. Foundations, penstocks, and spillway walls should be excavated with controlled blasting to leave competent final surfaces.

b. This chapter describes preferred blasting techniques used for surface excavations. Information was obtained from CE District offices and projects supplemented in less familiar procedures by references 8 and 14.

## 5-2. Blasting Patterns.

a. Hole Arrays.

(1) Hole array is the arrangement of blastholes both in plan and section. The basic blasthole arrays in plan are single-row, square, rectangular, and staggered arrays (Fig. 5-1). Irregular arrays have also been used to take in irregular areas at the edge of a regular array. The term "spacing" denotes the lateral distance on centers between holes in a row. The "burden" is the distance from a single row to the face of the excavation, or between rows in the usual case where rows are fired in sequence.

(2) Blasthole arrays in profile have characteristic hole depths and inclination. Fig. 5-2 shows how this geometry can vary. Deep and shallow holes are sometimes alternated to achieve particular results. Arrays using single holes are also used (Fig. 5-3).

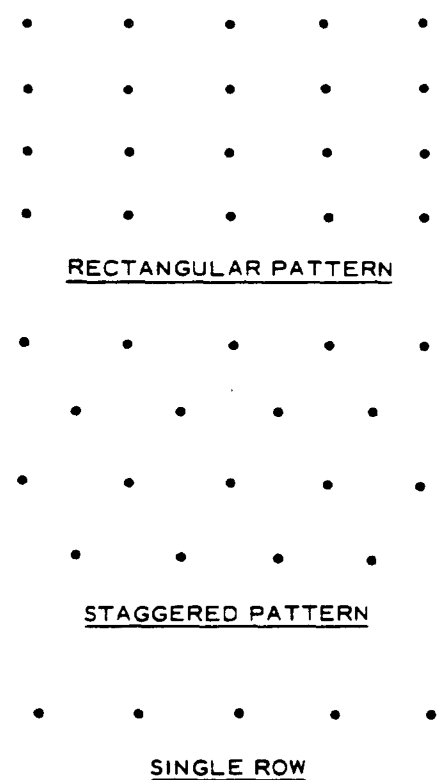



Fig. 5-1. Basic blasthole arrays

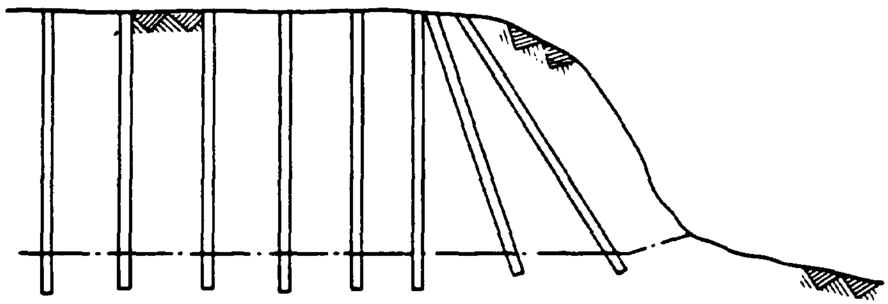
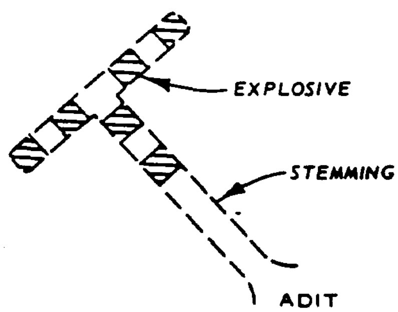
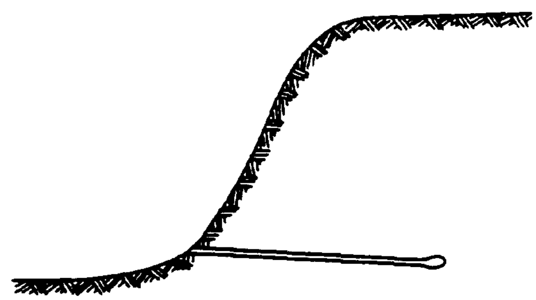


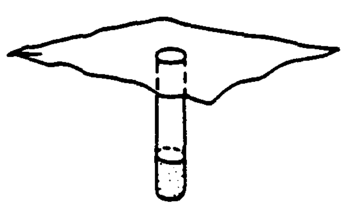
Fig. 5-2. Variation of regular arrangement of production blastholes as necessitated by topography




a. COYOTE TUNNEL (PLAN VIEW)
ALSO SEE FIG. 5-15



b. SNAKE HOLE (PROFILE VIEW)



c. POINT CHARGE

Fig. 5-3. Single-hole arrays

b. Delay Patterns. The order of firing charges in a round is determined by the delay sequence, which is regulated by either a delay electric blasting cap or a delay detonating cord connector (Chapter 3). By varying delays single-row, square, and staggered patterns can be modified as an aid in achieving fragmentation, throw, rock removal, or vibration control. Fig. 5-4 illustrates some possible delay patterns.

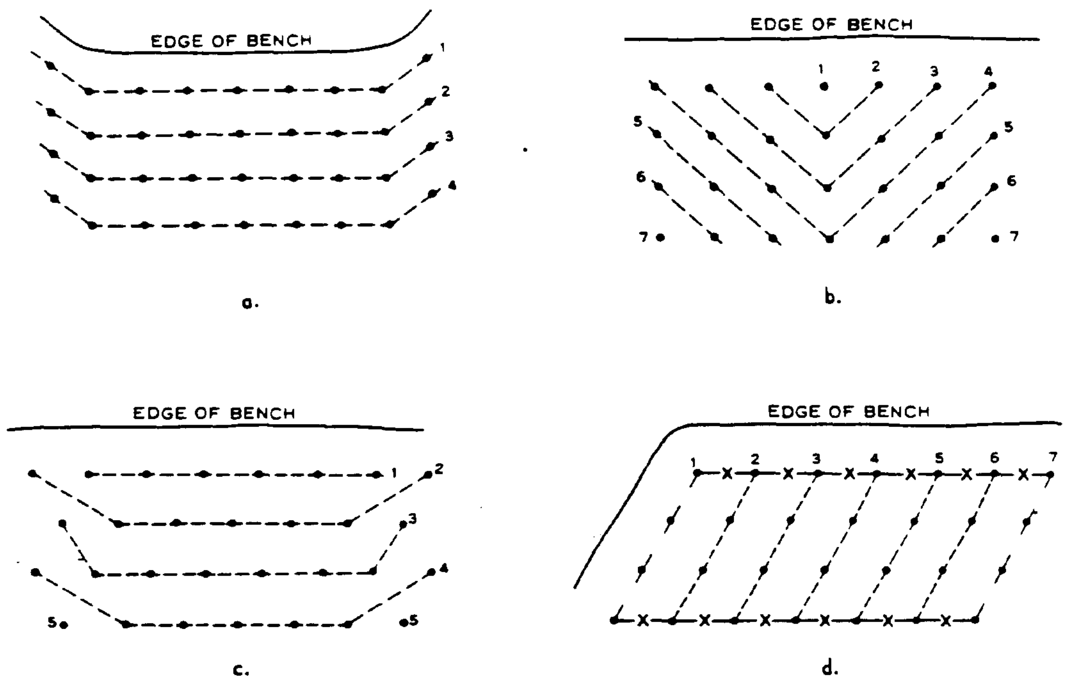



Fig. 5-4. Some possible delay patterns: a-c, with electric delays; d, with detonating cord connectors. x indicates position of detonating cord delay connector. Numbers indicate firing order

c. Arrangement of Charge in Hole.

(1) Blasting agents and explosives may be placed in the hole in solid columns or in decked columns, i.e. with segments of the charges separated by stemming. Free-running ANFO is poured into the hole on top of a primer. Additional primers are commonly placed in the column at 10- to 20-ft intervals. The charge is detonated with either electric caps inserted in each primer or with detonating cord down line tied in contact with each primer. In large holes the charge may be efficiently detonated by initiating only the bottom primer with detonating cord or blasting cap. Waterproof explosives or slurry blasting

agents must fill the wet portion of a hole before the free-running ANFO is loaded.

(2) Cartridged explosives are decked or threaded on a detonating cord down line and each cartridge is initiated by direct contact with the down line or by blasting caps. Presplit charges (para 5-4a) are string loaded or joined continuously in special long cartridges.

(3) Powder factor is the widely used term for the pounds of explosive necessary to blast a cubic yard (or ton) of rock. This simple ratio provides an approximation of the relative size of the charge in a hole or those in a round.

5-3. General Rock Removal.

a. Bench Blasting. The most common method of production blasting in quarrying and construction excavation is bench blasting. It involves inclined, vertical, or horizontal blastholes drilled in single- or multiple-row patterns to depths ranging from a few feet to 100 ft or more depending on the desired bench height. Where the excavation is shallow, i.e. less than about 20 ft in height, one level may suffice. In deep excavations, a series of low benches, offset from level to level, are recommended for operational convenience. Bench height is often two to five times the burden and the ratio of burden to spacing is often 1:1.25 to 1:2.0.

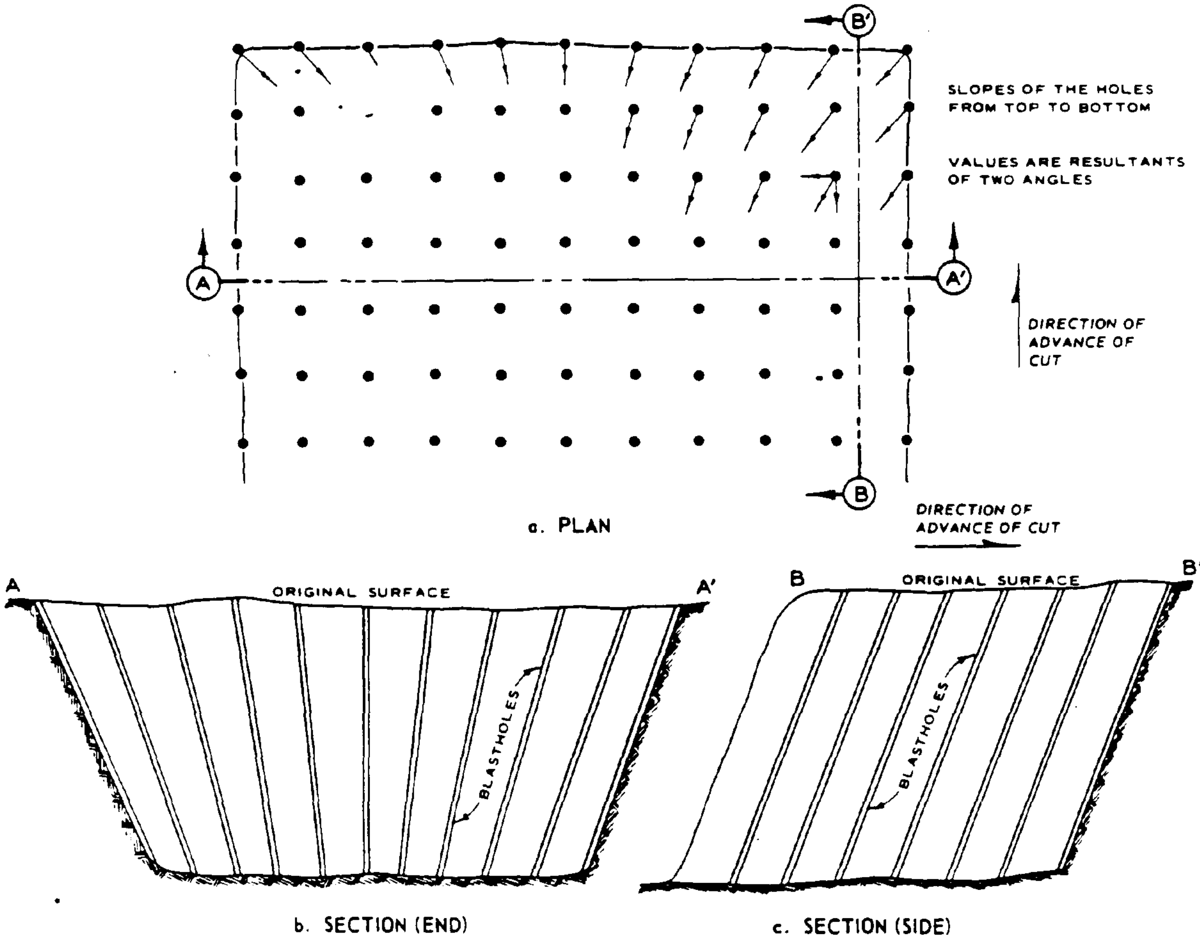
(1) Spacing and Burden.

(a) High quarry benches are usually blasted with large-diameter charges and large hole spacing. The rectangular array, with spacing between the holes greater than the burden, is considered most effective here. Common patterns for 5- to 6-1/2-in. holes in limestone are 14 by 20 ft (burden versus spacing) for 30- to 50-ft faces, and 16 by 24 ft for 50- to 70-ft faces.

(b) Lower benches, up to 40 ft, are commonly drilled with small-diameter holes (up to 4 in.), on a staggered or square delay pattern, from 6 by 6 ft to 12 by 12 ft. Narrow low benches are often blasted in a rectangular array of 4 by 10 ft to 6 by 9 ft depending on the rock type, borehole diameter, and explosive density.

(c) Some blasters use a rule of thumb that the burden should be between 20 and 40 times the drill-hole diameter.

(d) Another method of developing side and through cuts and benches is the trapezoidal array[15] in which holes fan out from bottom to top toward the sides of the cut (Fig. 5-5). This narrowing at the bottom gives an advantageous concentration of explosives at the toe. A disadvantage of this method is that the direction of each hole in a row is different and difficult to obtain.




*(Courtesy of Mining & Minerals Engineering)*

Fig. 5-5. Trapezoidal blasting pattern (after Babic[15])

(2) Advantages of Inclined Blastholes. Most bench blastholes are drilled vertically. However, blastholes inclined as low as 45 deg and paralleling the free face apparently use blast energy more effectively. Fig. 5-6 indicates the region of reflected tension waves is larger in inclined holes. Greater reflected blast energy results in more efficient fragmenting of the rock. In addition, the sloping bench face allows better displacement of the muck pile. Angles more than 30 deg from vertical are seldom used because of excessive drill bit wear and

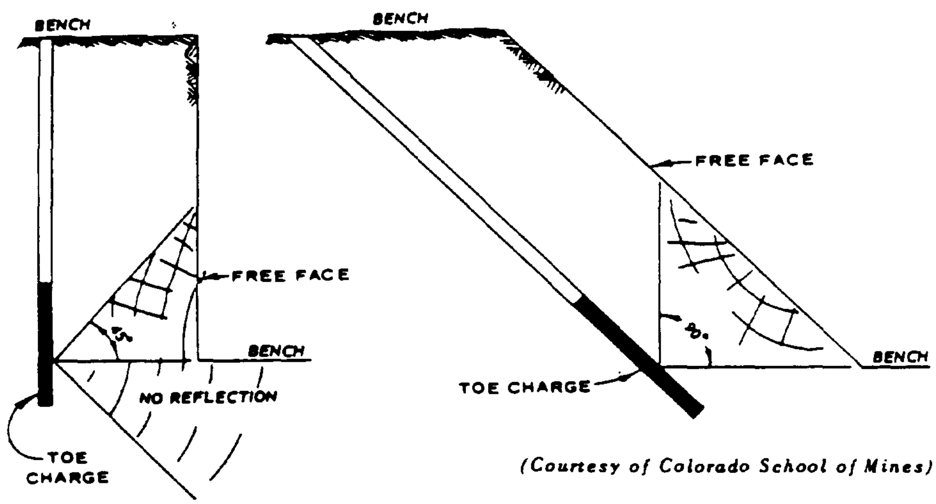



Fig. 5-6. Shock-wave propagation through rock generated by detonation of toe charge (after Kochanowsky[16])

difficulty in loading. Although further testing on use of inclined holes is necessary, the following advantages have been proposed:

(a) Increase in burden with depth is avoided (assuming bench face is not vertical).

(b) Loading factor may be reduced because of reduced resistance at the toe.

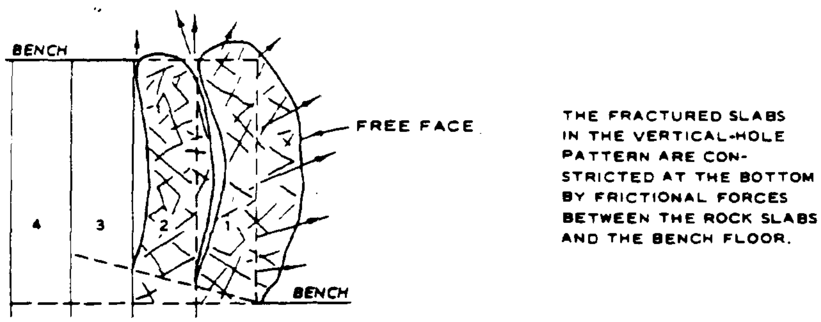
(c) Angle of breakage at the bottom is greater, making it easier to break and loosen the rock (Fig. 5-6).

(d) Previous muck piles are removed easily because of more freedom of movement (Fig. 5-7).

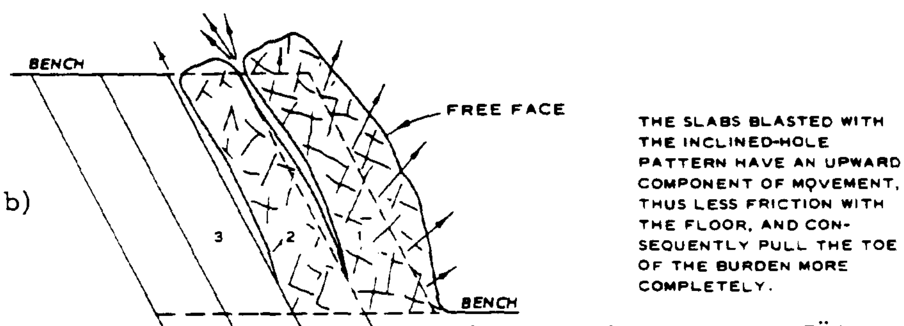
Despite their advantages inclined drill holes are more difficult to aline properly from an irregular ground surface.

(3) Lifters and Snake Holes. Rough terrain or loose overburden may prohibit drilling the bench from the top. In such cases lifters, nearly horizontal blasthole charges, may be used instead. Snake holes are similar to lifters except that they are always located at the toe of the slope. They should be inclined slightly downward (Fig. 5-8). They may also be supplemented above with rows of lifters inclined 20 to 30 deg upward from horizontal. The pattern is commonly fired in

(a)




(b)




*(Courtesy of Almqvist & Wiksell Förlag AB)*

Fig. 5-7. Bench-slab movement during blast with vertical (a) and inclined (b) holes (after Langefors and Kihlström[14])

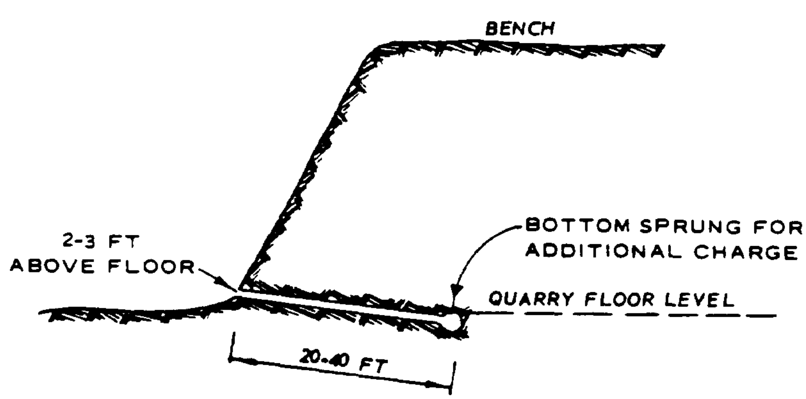



Fig. 5-8. Typical placement of snake hole

sequence, starting at the top. High quarry faces (75 ft and more) have been successfully blasted using a combination of snake holes and vertical holes. Lifters and snake holes are not commonly employed in structural excavation as their use generally requires that previously blasted rock be excavated before drilling can commence for subsequent rounds. Snake holes may produce excessive flyrock, and if they are drilled on an incline to below the final grade-line tolerance, the final rock surface is damaged.

(4) <u>Varying the Hole Array to Fit Natural and Excavation Topography.</u>

(a) Benches may be designed and carried forth with more than one face so that simple blasting patterns can be used to remove the rock. Fig. 5-9 shows a typical bench cut to two free faces and fired with one delay per row. The direction of throw of the blasted rock can be controlled by varying the delay pattern (Fig. 5-9a). The rock will

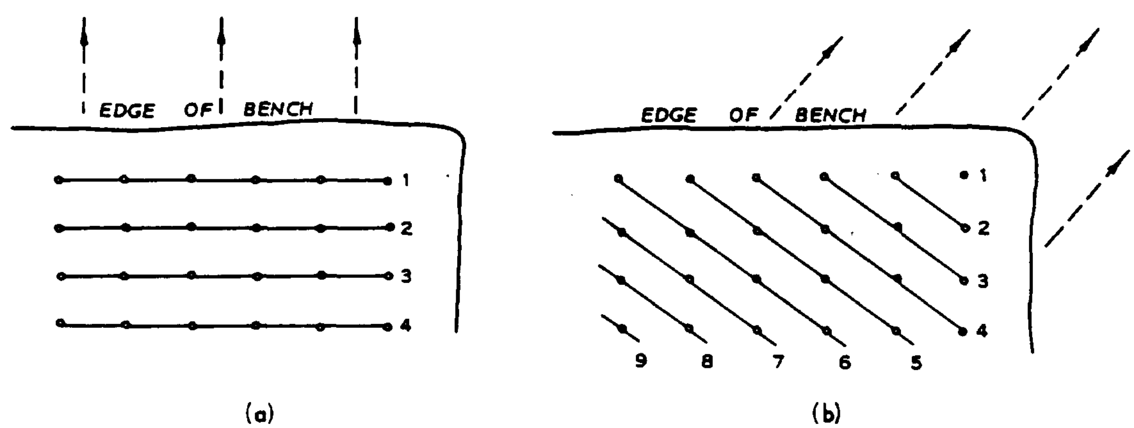


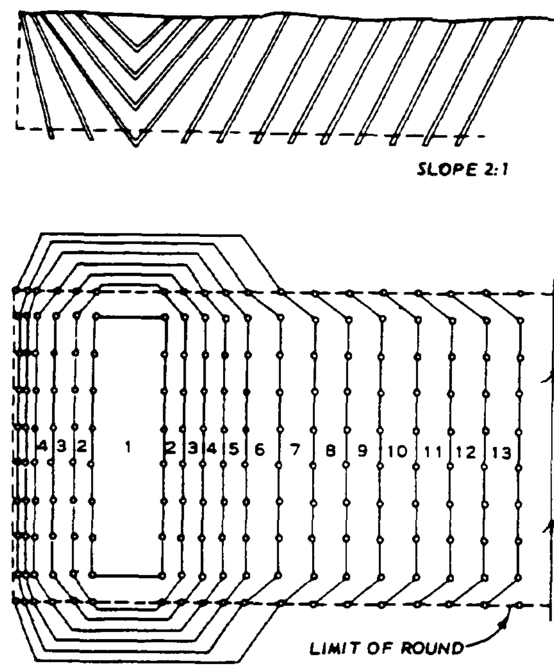

Fig. 5-9. Varying the direction of throw (arrows) by arrangement of delays (numbers)

move forward normal to the rows of holes. If the holes were fired in oblique rows (Fig. 5-9b) from right to left, however, the rock mass would be thrown to the right during blasting.

(b) The relations of delay systems to the drill-hole pattern should be considered an integral part of the blast pattern. Because of the change in direction of free faces toward which the rows will fire, the burden is decreased and spacing increased and the pattern is changed from square to staggered.

(c) Excavations can be opened by plow or deep "V" cuts where an initial cut is lacking. The cut is then enlarged in one of several bench levels. Fig. 5-10 shows a multiple-row round designed to open an excavation such as a foundation, wide bench, or road cut. Fig. 5-11 shows an elongated quarry blast pattern opened in the center and progressing toward each end by means of delays. This method may be used in deep through cuts 100 to 300 ft wide at the top. Where the cut becomes narrow, it may be worked from the center row outward toward the sides, as shown in Fig. 5-12.

(d) The depth of each lift or bench is usually about 10 to 30 ft with shallower depths considerably more efficient. With large or inclined holes the benches may be 50 ft or more in height but this should not be considered in structural excavation. Bench heights in cuts through hilly topography change continuously and burden and spacing must be modified accordingly. In Fig. 5-13 all holes bottom near the lower limit of intended breakage, but spacing, burden, and hole depth increase uphill to comply with the irregular ground surface.




(Courtesy of Almqvist & Wiksell Förlag AB)

Fig. 5-10. Multiple-row round including a V-cut opening. Rock in delay areas 1-4 is removed first to establish the free face (after Langefors and Kihlström[14])

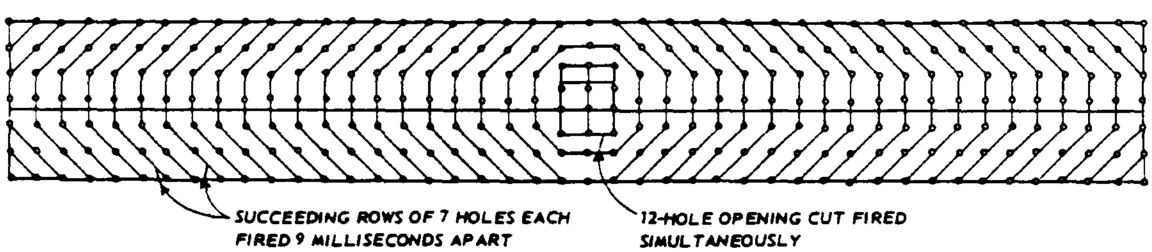



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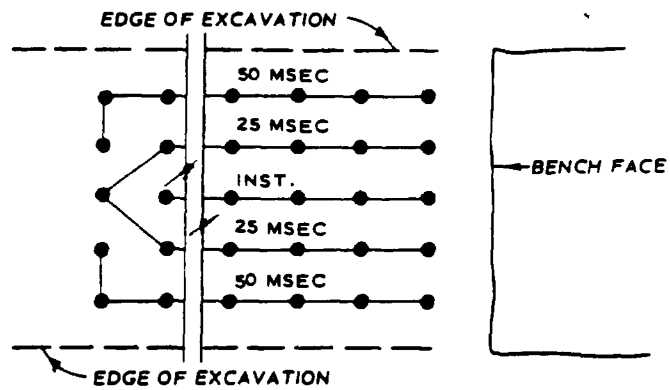
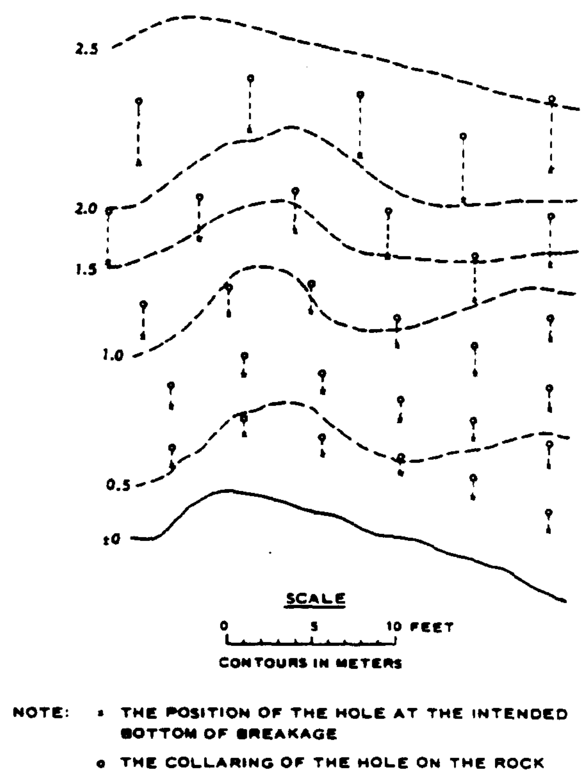
Fig. 5-11. Large quarry blast pattern measuring 600 by 100 by 48 ft. Illustrates how a single round accomplished what normally was done in 15 shots[17]




(Courtesy of E. I. du Pont de Nemours & Co.)

Fig. 5-12. Delays, in milliseconds, as shown (Du Pont[8])




(Courtesy of Almqvist & Wiksell Förlag AB)

Fig. 5-13. Distribution of inclined holes for a road cut in uneven topography. Regular hole array distorted to fit topography (modified from Langefors and Kihlström[14])

(5) Charge Distribution.

(a) Rounds in bench blasting should contain an optimum distribution and weight of explosive. The bottom few feet of the hole is usually loaded heavily with a dense, high-velocity explosive such as gelatin dynamite in order to pull the toe. The amount can be decreased if inclined holes are used.

(b) In dry holes, where a waterproof explosive is not necessary, free-running blasting agents can be used for the entire charge column if primed heavily at the bottom with a dense, high-velocity explosive.

(c) Table 5-1 gives charge concentrations for various hole diameters in bench blasting. Fig. 5-14 illustrates the loading of a typical inclined bench hole. The interval above the charge reduces excessive shatter of rock at the top[18] and normally can be decreased in smaller diameter holes. It is stemmed to retain gases and reduce noise and flyrock.

Table 5-1. Charge Concentration of Inclined Holes[(1)] for Single-Row Bench Blasting for Fragmentation with Respect to Various Burdens and Hole Diameters (Modified from Langefors and Kihlström[14])

*(Courtesy of Almqvist & Wiksell Förlag AB)*

| Hole Diameter in. | Concentration of Bottom Charge lb/ft | Concentration of Column Charge lb/ft | Total Bottom Charge lb | Max Burden ft |
|---|---|---|---|---|
| 1 | 0.42 | 0.17 | 2.1 | 3.8 |
| 2 | 1.7 | 0.7 | 17 | 7.8 |
| 3 | 3.8 | 1.5 | 57 | 11.5 |
| 4 | 6.7 | 2.7 | 130 | 15.5 |
| 5 | 10.5 | 4 | 260 | 19.5 |
| 6 | 15 | 6 | 440 | 23 |
| 7 | 20 | 8 | 700 | 27 |
| 8 | 27 | 11 | 1,100 | 31 |
| 9 | 34 | 13 | 1,500 | 35 |

Note: Values are only for an explosive with relative strength value = 1 corresponding to 35 percent nitroglycerin dynamite; relative strength of blasting gelatin = 1.27 and ANFO = 0.87.

(1) Slope is 2 to 3 vertical to 1 horizontal.

(6) Subdrilling. Blastholes are usually subdrilled where damage

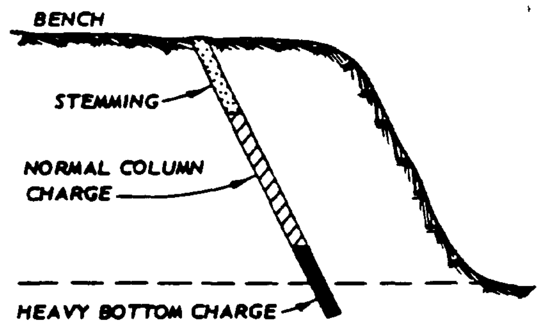



Fig. 5-14. Charge distribution in bench blasting. (See Table 5-1 for typical charge weights)

to the underlying rock is of no concern, and where no natural surface is available for horizontal control.[18] Depth below intended bottom may be 0.2 to 0.3 times burden to assure that the desired depth is reached. Inclined blastholes require less subdrilling to pull all the rock to bottom than do vertical holes (a(2) above). Because of the commonness of stress concentrations and consequent stability problems near the toe of the slope, overshooting there should be avoided.

(7) Secondary Blasting. Bench blasting ideally reduces all rock to a desired rubble size range. This is basic in order to facilitate handling of rubble, to meet limitations imposed by equipment, e.g., bucket size, or to produce a usable material. Actually, even a satisfactory blast may leave a few oversize blocks that must be broken by secondary blasting (pop blasting) or other means. Large blocks may be broken by blasting with light charges placed in small drill holes in the block. A quick method for smaller blocks, known as mudcapping, involves blasting with a part of a stick of powder placed against the block and covered with mud or a bag of sand. Light shaped charges are effective in block breakage also. Mudcapping and shaped charges may produce objectionable airblast, and breakage with a drop ball is preferred wherever that equipment is adequate and available.

b. Coyote Blasting, Trenching, and Cratering.

(1) Coyote blasting (gopher hole or tunnel blasting) is the practice of firing large charges of explosives placed in tunnels driven into a rock face at floor level. It is used where large quantities of material are to be removed cheaply. Coyote blasting works best in faces 75 to 175 ft high when using one level of tunnels. Higher banks can be blasted if the tunnels are supplemented with large blastholes to about one-third the depth of the face.

(2) A basic coyote layout consists of a main adit driven perpendicular to the face with wing tunnels driven left and right at 90 deg. The total round in the tunnels is split and placed in pits or on the floor commonly at 20- to 25-ft spacings. Fig. 5-15 shows a coyote layout with detonating cord tie-ins ready for detonation. The main tunnel should be stemmed completely with rock and other suitable material. Charges in the wings should also be stemmed, particularly where seams and partings are encountered or the burden varies greatly.

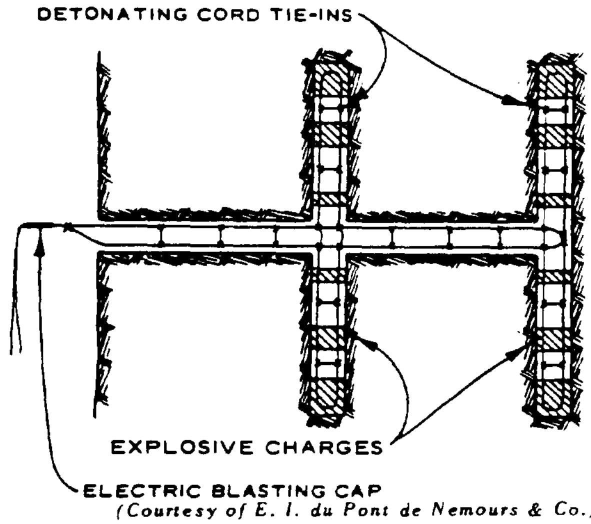



Fig. 5-15. Plan of coyote layout with detonating cord (after Du Pont[8])

(3) The loading varies with the tunnel layout and local depth. In general, the deeper the tunnel, the larger the charge. Current coyote blasting is done with bagged ANFO prills or dynamite. A review of large coyote blasting may help guide design of smaller, more routine coyote blasts; for example see reference 19.

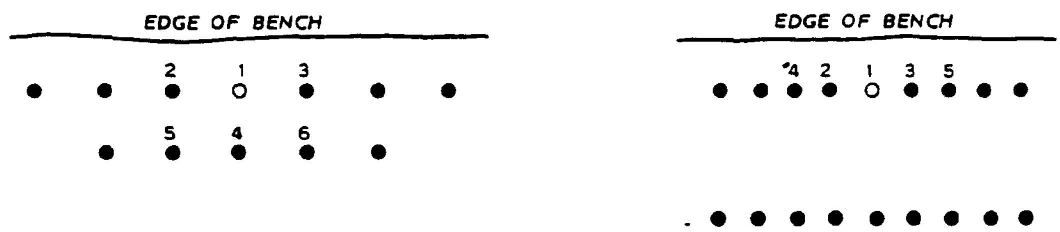
(4) Trenching steep-sided cuts through rock may be a useful blasting technique for culverts, pipelines, etc. The blasting only loosens material for subsequent removal mechanically. An initial blast of one or two holes creates a crater toward which succeeding delayed charges move the material. A single row of holes is used for narrow trenches; two staggered rows are recommended for trenches up to 5 ft wide; and trenches greater than 5 ft wide require additional rows of holes. Shallow trenches are commonly subdrilled 1 to 1-1/2 ft. Deep trenches should be blasted in lifts of 4 to 5 ft.

(5) Cratering, the technique in which large point charges will be used to excavate pits, quarries, and throughcuts, holds promise for the future. It is still largely in the developmental stage but at least one major canal in rock and soil has been excavated in this manner.[20]

c. Underwater Blasting. Blasting submerged rock is more difficult for the following reasons: confining pressure (hydrostatic) is high; holes are difficult to load after being drilled; vibration effects are more pronounced in water; most of the area cannot be observed and checked visually.

(1) Underwater Surface Shooting. Where hard rock overlies softer rock at shallow depth or only a few feet of soft material is to be removed, the "adobe" or underwater surface blasting technique may be used. Usually 50-lb charges of high-velocity, waterproof explosives such as 60 percent gelatin dynamite or slurry blasting agents, are placed on the surface of the rock in a regular pattern connected with detonating cord for simultaneous detonation. At least 25 ft of water is needed for confinement in some jobs but this will vary.

(2) Underwater Blasting in Drill Holes. Underwater blastholes are usually drilled from a barge. Hole diameters usually range from 2-1/2 to 6 in. depending on rock type and depth of cut. To insure proper depth of cut, blastholes are often drilled to the same depth below grade as the spacing between the holes. A commonly used depth below grade and hole spacing is 10 ft. A higher powder factor is usually required for underwater blasting. A square pattern of blastholes, with the same volume of rock per hole as an extended pattern (Fig. 5-16(a) and (b)), assures breakage of the rock by succeeding




(a)

SQUARE PATTERN. HOLE 1, DEFECTIVE, IS MISSED BY 2 AND 3 BUT BLASTED BY 4, 5, AND 6. FOR LARGE BURDEN AND BENCH HEIGHT.

(b)

EXTENDED PATTERN. HOLE 1, DEFECTIVE, MAY BE TAKEN OUT BY 2, 3, 4, AND 5, BUT WILL BE UNAFFECTED BY THE SECOND ROW OF HOLES. GOOD FOR LOW BENCHES.

*(Courtesy of Almqvist & Wiksell Forlag AB)*

Fig. 5-16. Blasthole patterns for underwater blasting (after Langefors and Kihlström[14])

rows of holes even if a defective hole fails to fire in the front row, provided the holes are drilled to a sufficient depth below grade and charged heavily enough to pull the added burden of the unfired hole.

5-4. Excavation for Control of Rock Surfaces. Overbreakage and fracturing from excavation blasting often necessitate the removal (scaling) of loose material beyond the designed face and placement of an additional amount of concrete. In addition, blast damage to the final rock face may cause instability and rockfall hazards. For these reasons, among others, controlled blasting is indispensably routine in excavation for structures and elsewhere. Controlled-blasting techniques minimize overbreakage and permit steeper slope designs because of increased mechanical stability and resistance to weathering. They also reduce deeper fracturing and weakening of the finished excavation. The techniques can be used to cut an excavation to accurate lines and around vertical and horizontal corners. Improved appearance of rock slopes may also result. Three controlled-blasting techniques in use today are presplitting (Fig. 5-17), smooth blasting, and line drilling.

a. Presplitting. A presplit surface is initiated along the excavation line by blasting instantaneously a single row of closely spaced drill holes prior to detonating the main rounds. The presplit surface reduces enough of the blast effects of the main round to reduce damage in the rock beyond it. Ideally a single fracture connects adjacent blastholes (Fig. 5-18), and half of the hole (cast) remains at each presplit hole. Excessive crushing and radial cracking at the periphery or between holes are indications that the charges should be reduced. Supplemental adjustment of hole spacing may also be necessary. Formation of the presplit fracture is influenced by borehole spacing, with the closer spacing forming a more prominent fracture. Because of the high cost of drilling, the optimum spacing is the largest at which radial cracks will join and form a continuous undamaged surface.

(1) Design of the Presplitting Layout.

(a) Critical factors in successful presplitting, other than excavation slope design, are hole diameter and spacing, hole deviation, charge distribution, and confinement. Preblast field testing may help to determine optima for each job. Competent and homogeneous rock usually permits greater spacing, while the hole diameter is usually smaller in hard rock than in soft (para 6-2). Presplitting holes usually are double loaded at the bottom to insure splitting to the full depth, but some blasters question the value of heavier bottom loads.

(b) Review of data from 35 successful presplitting operations indicates that a spacing of 24 in., center to center, and a hole diameter of 3 in. were used most often (Table 5-2). Charges were usually 1-1/4- by 4-in. half-cartridges of 40 percent gelatin or ammonia gelatin dynamite taped at 1-ft intervals (intervals as much as 3 ft have been used) to down lines of detonating cord with one or two 1-1/4- or 1-1/2- by 8-in. sticks at the bottom. This amounts to about 1/4 lb

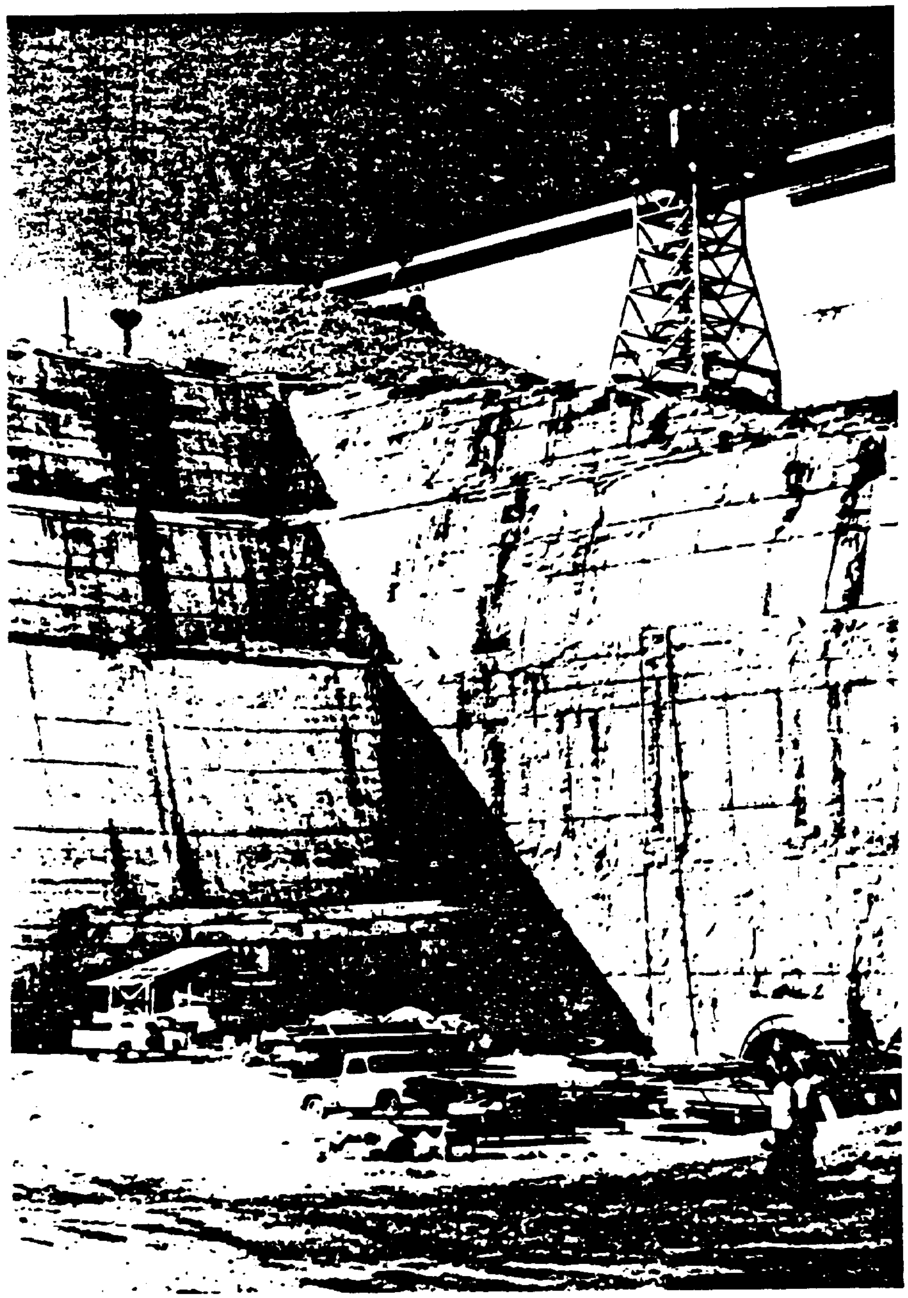


Fig. 5-17. Presplit blasting in limestone for a powerhouse

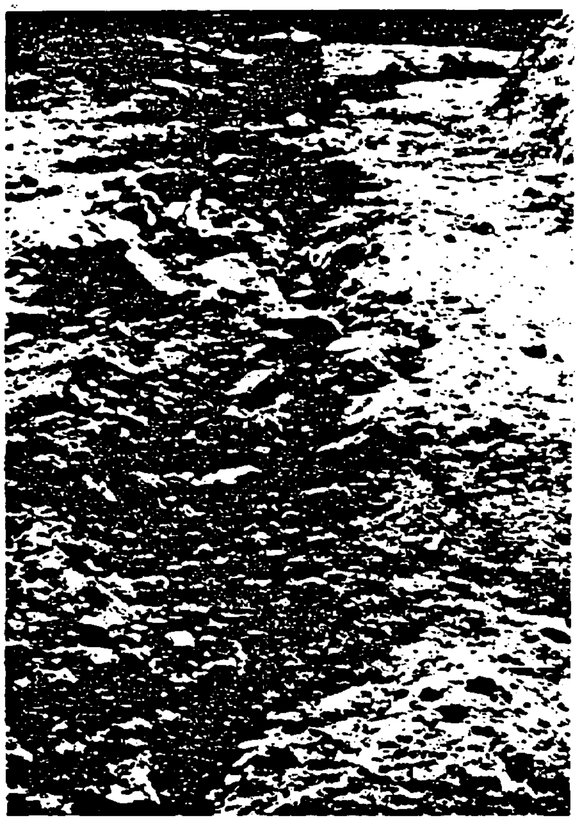


Fig. 5-18. Presplit fracture

Table 5-2. Most Commonly Used Presplitting Arrangements[1] (Results of 35 Sample Analyses)

| | Hole Spacing in. | Hole Diameter in. | Charge[2] | Explosive |
|---|---|---|---|---|
| Mode | 24 | 3 | 1-1/4- by 4-in. sticks at 12-in. intervals | 40 percent gelatin or ammonia (extra) gelatin dynamite |
| Range | 16-48 | 2.5-4.5 | -- | -- |

(1) Hole spacing will be less for lifts of less than 6 ft.
(2) Although 1-1/4- by 4-in. sticks have been used commonly in the past, long narrow cartridges are becoming prevalent (see text) in current use.

of dynamite per foot of hole; however, lighter loads would probably be better in weak rock masses. Stemming consisting of 3/8-in. clean stone chips or fine gravel should be poured around the charges and should fill the top 3 to 4 ft of hole. Fig. 5-19 illustrates presplit blast-holes loaded and ready for firing. The detonating cord down lines from each hole are tied to a trunk line. The trunk line leads at each end to electric blasting caps.[21]

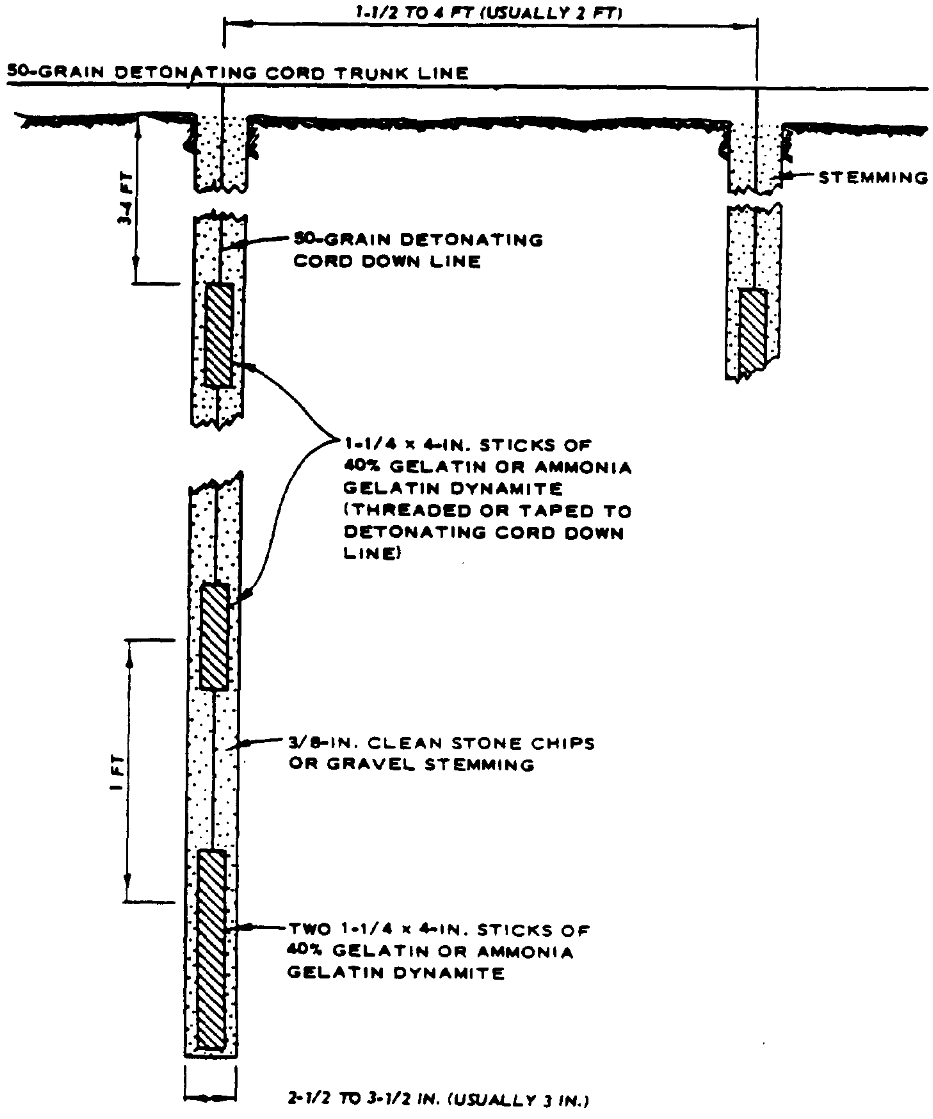



Fig. 5-19. Section of typical presplit holes ready for firing

(c) Explosives packaged in cardboard tubes that can be coupled into a continuous column as they are placed in the hole can be used in place of the string loads. Such long narrow cartridges (i.e. 1 by 36 in. and 3/4 by 24 in.) are becoming prevalent in current practice. They give better powder distribution and lessen the chances of crushing rock at the perimeter of the borehole. Loading time is also reduced considerably and contractors should be encouraged to use them.

(d) Hole depth in presplitting is limited by the difficulty in drilling accurately alined holes which, in turn, is dependent on the quality of the rock mass. When more than one level of presplitting is necessary, a 1-ft bench offset is usually left between lifts by the drill setup. Presplit holes are commonly 25 to 40 ft deep. Holes exceeding 40 ft should not be permitted unless it can be demonstrated that accurately alined holes will be achieved. It is essential that the holes start and remain in the presplit plane; therefore care must be exercised, first, in establishing the trace of the plane on irregular ground surfaces and, second, in maintaining the correct inclination and direction of the holes. Templates are often useful in achieving correct drill setups.

(e) Presplit blastholes loaded with gelatin dynamite can be either wet or dry. Wet holes tend to increase occurrences of bridging of stemming material such as drill cutting, overburden, or clay. Only clean stone chips or screened gravel should be used. Either angled or vertical holes may be used, as long as they are kept parallel by using a clinometer. The deviation of holes from the designed plane should not be greater than 6 in. at the bottom and for close hole spacing should be much less.

(2) Relation to Main Blast. Presplitting and primary blasting are sometimes performed in one operation with the presplit and primary holes drilled and loaded at the same time. Delays of 100 to 200 msec separate the two blasts. This method reduces time needed to set up drilling equipment. Usually, however, the line of presplit holes is drilled ahead of the main blast pattern as shown in Fig. 5-20. The final row in the primary pattern is commonly kept 3 to 4 ft from the presplit row. A delay pattern designed to provide maximum relief to the main blastholes nearest the presplit line should be used for the primary blasting. Delays sequenced parallel to the presplit may reduce damage in the permanent wall (see d(3)(c) below). The presplit surface should be kept about half the length of the primary pattern ahead of the main blast area so that subsequent blasts can be altered to fit changing rock conditions. Lighter loading of holes of the main charge near the presplit may reduce damage to the wall (d below). In special cases where the confinement (burden) is not sufficient, smooth blasting may be applicable (b below).

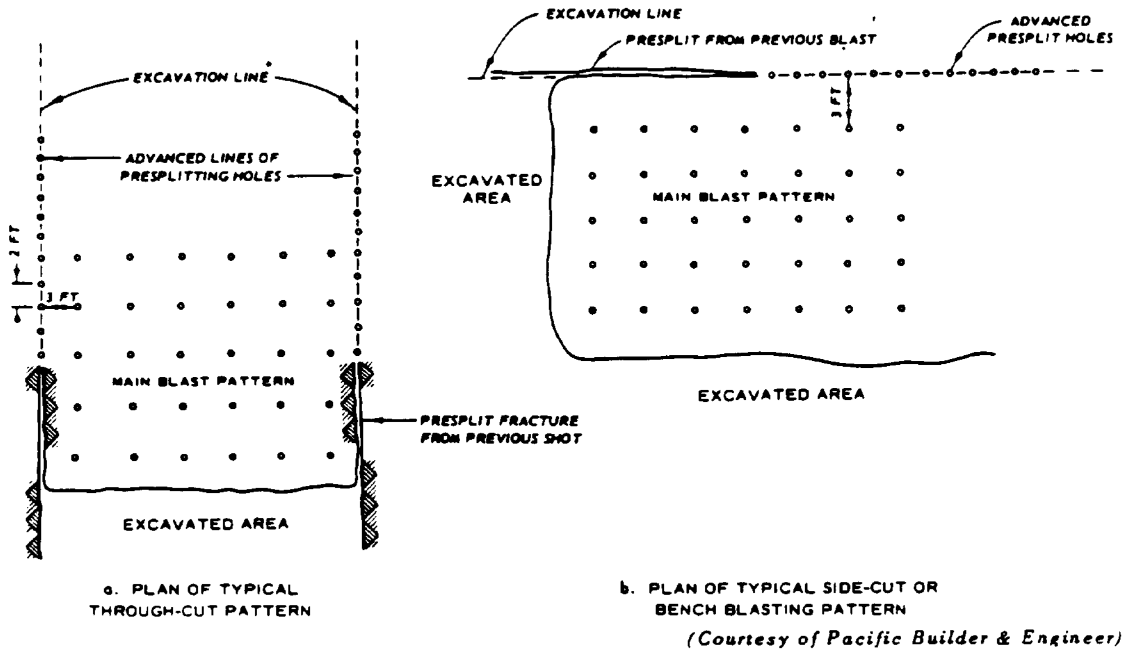



Fig. 5-20. Relation of presplit to main pattern (after Veith[22])

(3) Presplitting Horizontal and Vertical Corners. Presplitting corners is a major problem. Battering is not always acceptable and right angles are required. On inside corners the presplit fracture often propagates into the adjacent wall, and on outside corners the right angle is difficult to attain and preserve. One method involves placing one of the loaded holes at the corner. Another method utilizes unloaded guide holes at one-half spacing, in place of loaded holes (Fig. 5-21) in the vicinity of the corner, but some CE and Bureau of Mines personnel feel that such guide holes have little value. Some CE project specifications require line drilling (c below) at the corners.

(4) Horizontal Presplitting. Presplit holes may be carried into a steep face to form a horizontal fracture above the existing floor.[23] Normal vertical holes may break below the required grade, so a horizontal row of holes, about 3 in. in diameter and spaced about 24 in. apart may be preferred. Horizontal presplitting and subsequent excavation blasting form an acceptable bench at the desired level. The technique should be considered in grade excavation along a rock cliff where it is particularly important to preserve the edge and avoid excessive fill downslope.

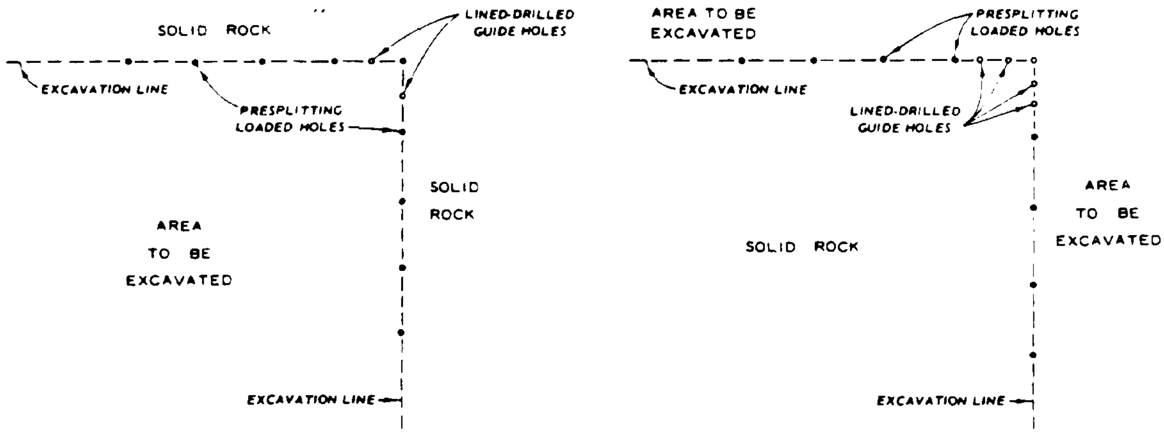



Fig. 5-21. Use of guide holes in presplitting inside and outside corners (after Du Pont[8])

b. Smooth Blasting.

(1) In smooth blasting a narrow berm is left to reduce damage to the final wall by the main blast. This berm is subsequently removed by firing small or lightly charged holes along the neat excavation line. Smooth blasting may also be used for trimming natural slopes to grade in the special case where burden is low. The technique should not be regarded as a substitute for presplitting. Cushion blasting is a special case of smooth blasting in which considerable air space or stemming surrounds charges in the holes and serves to reduce undesired blast effects in the final wall. Hole spacing for smooth blasting should always be less than the width of berm (burden) being removed (Table 5-3). Charges, commonly 8-in. cartridges of dynamite, are string-loaded 1 to 2 ft apart on detonating cord down line or placed in the hole through loading tubes. The space between and around charges and the top few feet of hole are stemmed. A bottom charge two or three times that of the others should be used to insure splitting there.

(2) The depth of blastholes is limited by drilling accuracy. Deviation at the bottom should not exceed 6 in. Holes as deep as 90 ft have been drilled, but normally excavations over 60 ft in depth are blasted in two lifts or more.

c. Line Drilling and Close Drilling.

(a) Line drilling consists of placing a row of unloaded drill holes along the excavation line spaced on centers no more than two times the

Table 5-3. Some Typical Hole Spacings and Diameters, Charge Concentrations, and Burdens for Smooth Blasting (after Langefors and Kihlström[14])

| Drill Hole Diameter in. | Charge Concentration lb/ft | Spacing ft | Burden (thickness of berm) ft |
|---|---|---|---|
| 1-1/2 | 0.08 | 2 | 3 |
| 2 | 0.17 | 2-1/2 | 3-1/2 |
| 2-1/2 | 0.23 | 3-1/2 | 4-1/2 |
| 3 | 0.34 | 4 | 5-1/2 |
| 3-1/2 | 0.5 | 4-1/2 | 6-1/2 |
| 4 | 0.6 | 5-1/2 | 7 |

*(Courtesy of Almqvist & Wiksell Förlag AB)*

hole diameter. These form a surface of weakness to which the primary blast can break. They also reflect some of the shock waves. Increased use of presplitting for economical reasons has relegated line drilling to a supplementary role. Line drilling may be required prior to presplitting for at least 10 ft in both directions from a 90-deg corner. In this procedure the depth of presplit holes must not exceed that of the line drill holes.

(b) In line drilling the primary blasting is conducted to within two or three rows of the line-drilled row to decrease the burden. The row of primary blastholes nearest the line-drilled row should have 75 percent of the usual hole spacings and should be 50 to 75 percent closer to the line-drilled row than to the last primary row (Fig. 5-22). The powder factor should be reduced.

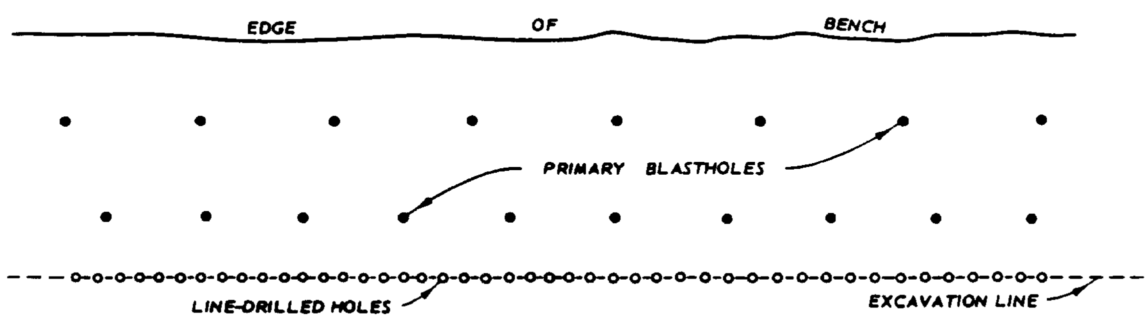



Fig. 5-22. Typical arrangement of line drilling with respect to main blastholes

(c) Because of the tedious drilling necessary, line drilling is most useful in easily drilled homogeneous rock. Despite high cost, line drilling has application in areas where even presplitting may cause excessive wall damage, and it may be required where other structures were adjacent to an excavation.

(d) Close drilling may be specified for finished surfaces not requiring line drilling. Close drilling consists of holes spaced farther apart than line-drilled holes but closer than presplit holes. They may be loaded or unloaded as specified.

d. Precautions in Approaching Final Excavation Surfaces.

(1) Precautionary measures are practiced in an effort to minimize damage beyond the final excavation surface. Subdrilling on berms and final foundations should not be permitted. Some CE specifications require that upon approaching within 15 ft above grade for a concrete dam foundation, blastholes must not be loaded below two-thirds the distance to grade. This in effect reduces the last two regular lifts to 10 and 5 ft (or less) and necessitates a reduction in hole spacing. Subsequent final trimming to grade is usually accomplished with wagon drills or jackhammers and very light charges.

(2) In horizontally stratified rock, special care should be exercised to avoid opening a bedding surface at a comparatively shallow depth below grade by blasting above grade. Such a surface, created by the spalling mechanism (see para 2-3b), may be a very real but unknown hazard to the safety of a concrete dam since it postdates foundation exploration. The phenomenon can occur despite restrictions such as those mentioned above.

(3) Presplit surfaces are preserved by one or more of the following precautions taken in the main blast:

(a) The outside rows may be loaded lighter to reduce vibration and fragmentation.

(b) Berms may be left adjacent to the presplit for later removal.

(c) The delay pattern may be arranged to progress parallel to the presplit (Fig. 5-23) in order to avoid excessive back pressure beyond the presplit.

5-5. Blasting for Control of Rock Sizes. Heavy construction usually requires rock for fills, aggregate, or riprap. Blasting must be designed to produce the proper size and grades of fragments for these

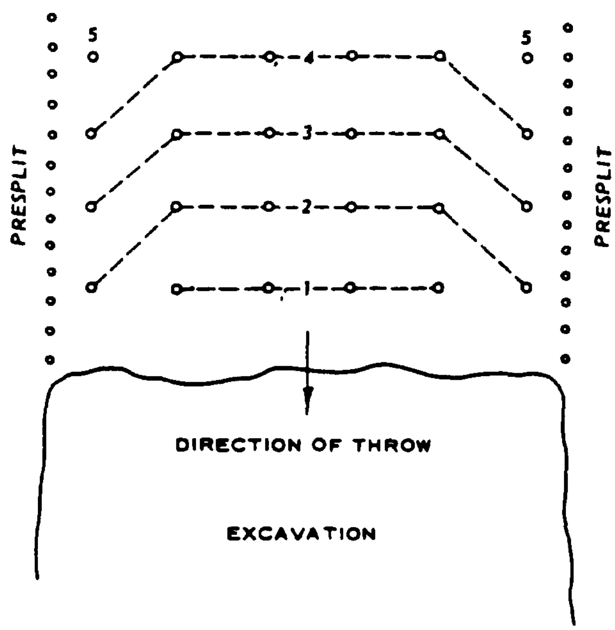



Fig. 5-23. Main charge delays, in numerical sequence progressing parallel to the presplit, reduce back pressure in wall

rock requirements. Maximum fragment size gradation can be estimated by studying the spacing of joints in bedrock or size of talus produced from outcrops.

a. Riprap. The degree of fragmentation in blasting for riprap must be controlled so that proper size and gradation can be obtained. Coyote blasting may be used for producing large rocks for riprap and breakwaters quickly and economically (see c below). In some rocks, low-velocity ammonia dynamites are used because of their low shattering effects. ANFO, while often detonating at a higher velocity than many low-velocity ammonia dynamites, is also used, largely due to its lower price per pound. However, coyote blasting seldom yields well-sorted rock for riprap, and secondary blasting (mudcapping or blockholing), as well as screening off of fines, may be necessary. Restraint should be exercised in considering the coyote method for jetty stone. Jetty stone quarries commonly contain only about 10 to 20 percent of the best grade large stones and the excessive fracturing and poor control of a coyote blast can ruin a quarry. Depending on their availability, it may be advantageous to mine these stones one by one by multiple-row or irregular array.

b. Aggregate.

(1) Material used for concrete aggregate usually is of small sizes, and therefore blasts should be designed to produce a high degree of fragmentation and thereby reduce handling and crushing costs.

(2) Good fragmentation is commonly achieved by adequately charged, staggered holes in a pattern utilizing the optimum spacing/burden ratio and detonated by a millisecond delay system (Fig. 5-24). Staggered holes allow more of the rock to be affected by the blast and thus produce better breakage throughout. The spacing should

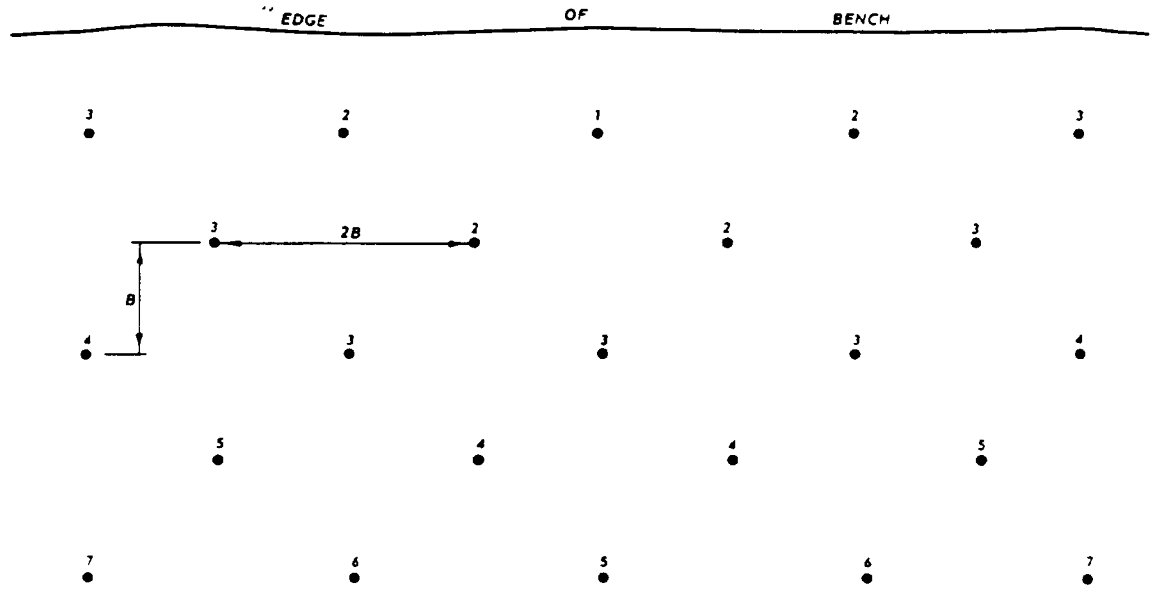



Fig. 5-24. Plan of blasthole pattern for fragmentation of rock to produce aggregate

normally be 1-1/2 to 2 times the burden.

(3) Explosives with high detonation velocity and consequent shattering power are most effective for fragmentation. However, cheaper blasting agents at wider spacing, if properly boosted, fragment well and are usually used.

(4) Small holes (1-1/2 to 4 in.) at closer spacing distribute the explosive and produce better breakage, especially at the top where good fragmentation is difficult to achieve in some rocks.

c. Rock Fill for Dams.

(1) Rock fills commonly consist of all rock fragments below a specified size. A rock fill is most stable and solid if the rock fragments are angular, the largest pieces are smaller than the depth of the lift, and the sizes are well mixed to include a suitable proportion of fines.[24]

(2) The production of fill can be most easily controlled by using vertical or inclined blastholes and changing the patterns to meet varying rock conditions.

(3) Coyote blasting is also used for rock-fill production because of its economy and speed. Coyote blasts may yield an excessive amount of fines and dust, however, and these may have to be removed by screening. Elsewhere, oversized material may result and this must be broken by secondary shooting or otherwise removed.